Extremely High-Contrast, High Spectral Resolution Spectrometer REACH for the Subaru Telescope

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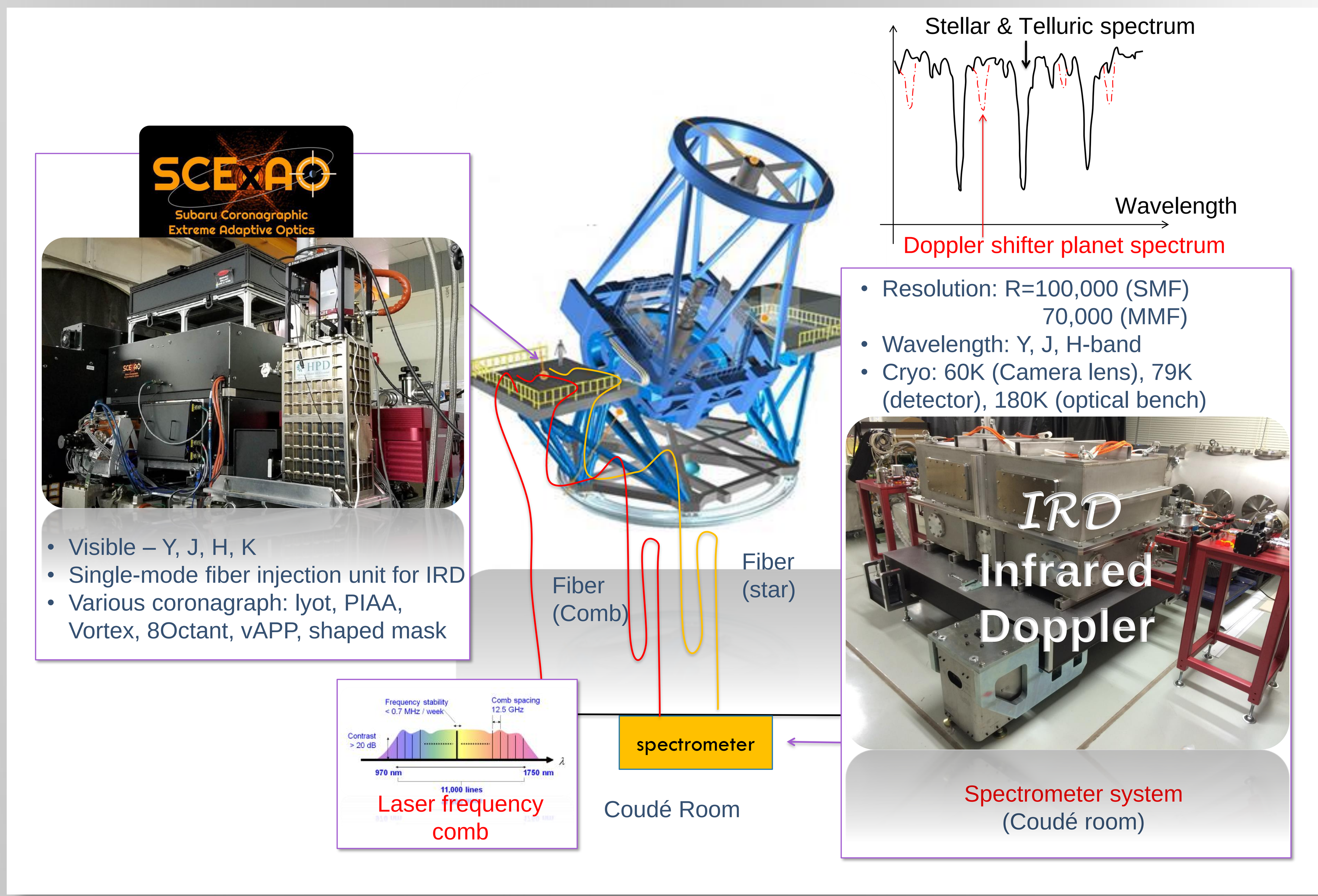

Figure 1: General view of SCExAO, IRD, and the Subaru telescope

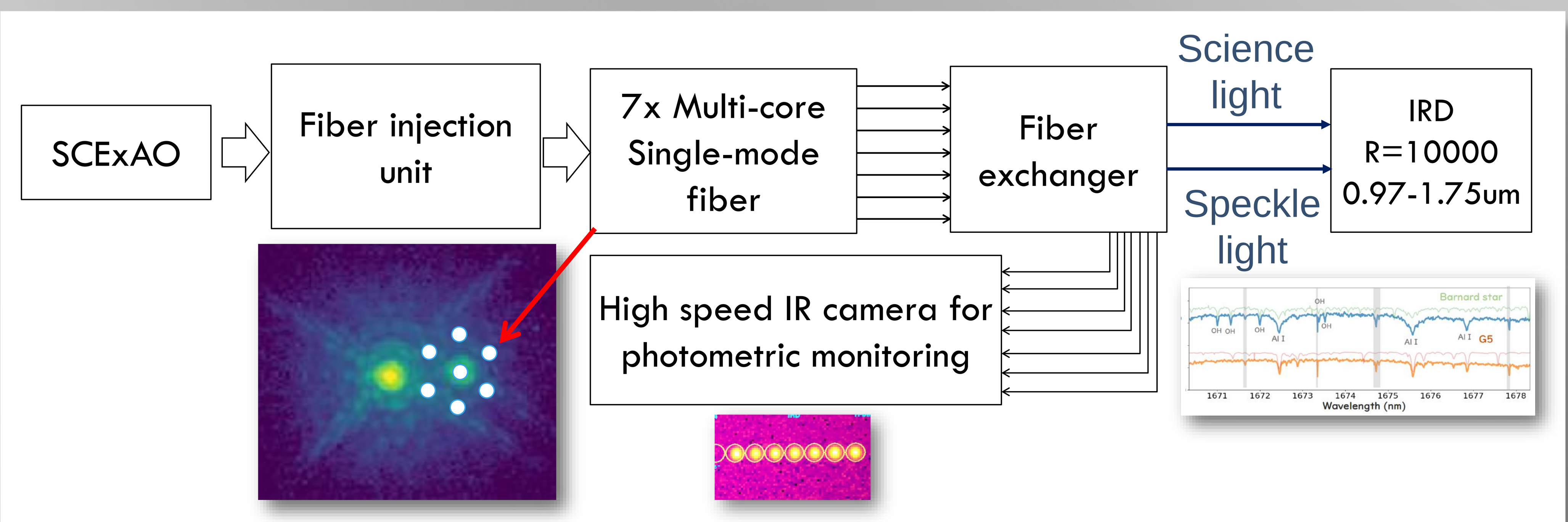

Figure 2: Schematic view of the REACH system

SCIENTIFC BACKGROUND

Detection of molecular species in exoplanetary atmospheres fundamental to their characterization. In recent years, the technique of directly detecting the pattern of the molecular lines through cross-correlation analysis have succeeded the detections of molecules by high-dispersion spectroscopy with the spectral resolution ~ 100,000. Given the next goal of detections of molecules in cold exoplanets or ultimately on Earth-like planets in the TMT era, a technical breakthrough is required to promote this method further. That is a combination of an extreme-AO (ExAO) coronagraph and a NIR high-dispersion spectrograph. The ExAO coronagraph prevents the scattered light from a central star and significantly increases the signal to noise of the light into the high-dispersion spectrograph. We proposed a method to detect planetary molecules from the earliest with the combination of ExAO coronagraph and high dispersion spectroscopy (Kawahara+2014, ApJS, 212, 27, Jovanovic+2017, OFC WH3.3, Jovanovic+2017 Ao4ELT, Lozi+2018 SPIE 1070359) and developed a system to combine the SCExAO with the NIR spectrometer (IRD) on the Subaru telescope.

The system, REACH(Rigorous Exoplanetary Atmosphere Characterization with High dispersion coronAgraphy), is the on-sky testbed of such systems (Fig. 1). Also, REACH provides a great opportunity to expand the science of the self-luminous exoplanets through significant suppressing of the starlight by ExAO coronagraph, including search for signals of new molecules (methane, FeH, VO, and so on) and also detecting planet kinematics such as a planet spin.

REACH = SCExAO+IRD

Fig. 2 shows the schematic view of the REACH system. A fiber injection unit, consisting of a pick-off mirror, an off-axis parabola with piezo actuators, and a multicore fiber, is located on the SCExAO optical bench. The collimated beam from the SCExAO, which has 8.8 mm diameter, is focused on to the MCF by the off-axis parabola (Thorlabs MPD124-M01), which has 43.4 mm parent focal length. The multicore fiber (from Chiral Photonics Inc.) is a fiber bundle consisting of seven single-mode fibers (SMF), which has a 10.4 μm Mode Field Diameter (MFD) at 1550nm and hexagonally packed with 37 μm fiber-to-fiber separation (Fig. 2). The central fiber is used to couple the light of a science object, and the surrounding six fibers (speckle fiber hereafter) will accept scattered light from a bright object like a parent star of an exoplanet. All SMFs in the MCF are connected to the output fibers, OFS BF05635-02, which has 7.7 μm MFD, the same fiber used for IRD SMF.

The output of the central fiber and one of the speckle fibers are connected to the fiber switching instrument (fiber switcher). In the fiber switcher, two fibers from the MCF can be connected to multi-mode fibers (MMF) going to the photometric monitoring camera for measuring injected light intensity with a high-speed NIR camera (C-RED2 camera) in the SCExAO for optimization of fiber coupling by adjusting a tip-tilt of the off-axis parabola. Once the fiber injection efficiency is optimized, the fiber switcher connects two SMFs going to the IRD spectrometer to the two MCF in order to observe spectra of a science object and the speckle light simultaneously. Furthermore, the fiber switcher can inject calibration light from the laser frequency comb or ThAr lamp to any of two IRD SMFs for spectrometer calibration for precise radial velocity measurements. The remaining five speckle fibers are always connected to the photometric monitoring system to obtain information on WF correction quality of the SCExAO. In the future, a new fiber switcher under development will enable to select one of any six speckle fibers to send appropriate speckle light to IRD.

ON-SKY RESULTS

Fig.3 shows the total throughput of REACH. This throughput was obtained under 0.6 arcsec seeing condition for a V=5.9 mag star. We estimated ~50% fiber coupling efficiency around the -H-band. The shorter the wavelength, the worse the total throughput is due to the AO performance and the spectrometer's efficiency. Fig. 4 depicts the image of the moderate contrast binary system, HIP18413 obtained with the C-RED2 camera (left) and the spectrum of each component (right). The contrast between the primary and the secondary component is 4 in the H-band, 10 in the J-band, and the angular separation is 0.4 arsec. One can see that the spectral type of the primary and the secondary star is G5 and M5, respectively by comparing a template spectrum and the observed spectrum. It is also shown that many absorption lines are clearly resolved, and it will allow us to measure the radial velocity of both stars accurately.

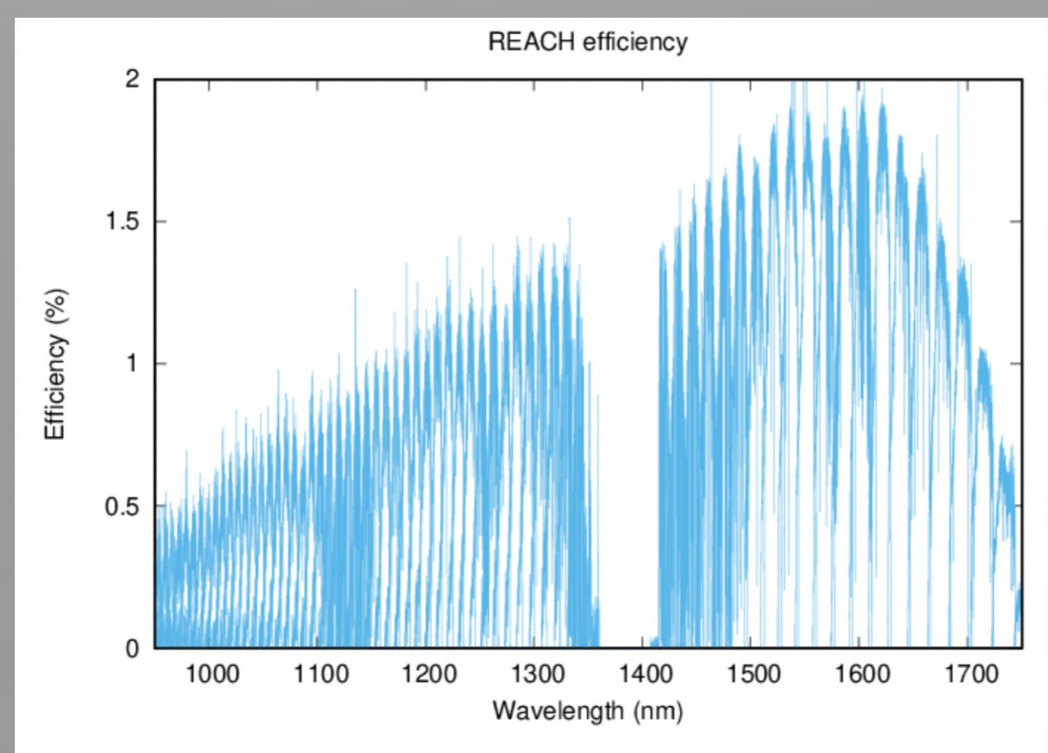

Figure 3: Total throughput of REACH

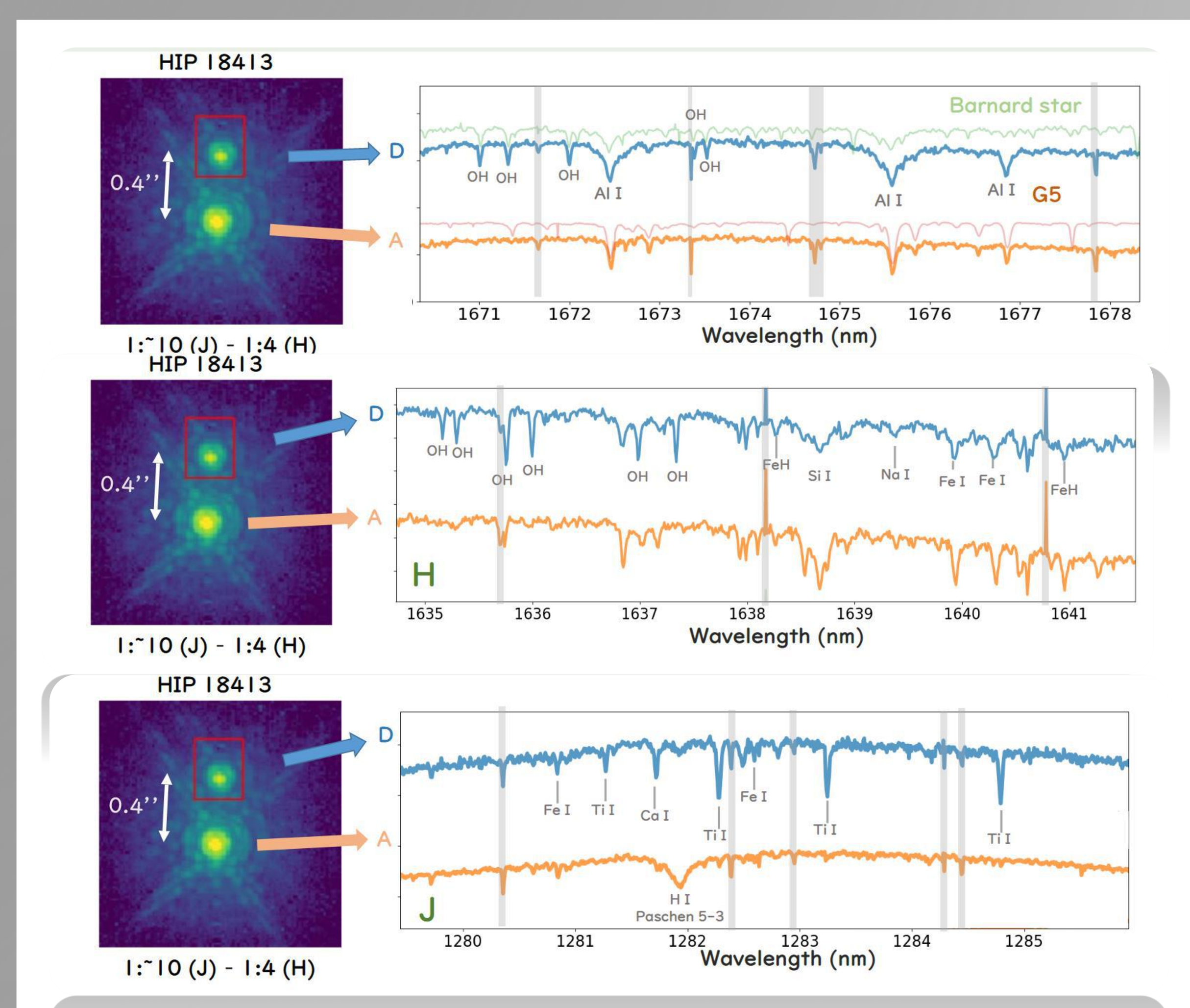

Figure 4: Spectra of each component of HIP18413